



Wide-field Imaging System and Rapid Direction of Optical Zoom (WOZ)  
(Contract Number N00014-10-C-0194)

Quarterly Technical Report #1  
16 June 2010 - 15 Sep 2010

Submitted by  
Kratos Defense and Security Solutions

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September 22, 2010

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SUBJECT: Contract N00014-10-C-0194, “Wide-field Imaging System and Rapid Direction of Optical Zoom (WOZ)”

Dear Dr. Duncan:

In accordance with the Contract Data Requirements List (CDRL), Data Item A001, of the subject contract, the first quarterly technical and non-technical reports are attached.

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Sincerely,

A handwritten signature in black ink that reads "Judy Staggs". The signature is fluid and cursive, with the first and last names clearly legible.

Judy Staggs  
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Quarterly Technical Report #1 (QTR-1)

**Wide-field Imaging System and Rapid Direction of Optical Zoom (WOZ)  
QTR-1**

Contract Number  
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Submitted by  
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## **Abstract**

This report covers technical progress on the Wide-field Imaging System and Rapid Direction of Optical Zoom (WOZ) contract for the period 16 June – 15 September 2010. A report covering financial status for this period is provided separately. During this period, subcontracts were awarded by the prime to both team mates, Advanced Optical Systems, Inc. and NeXolve, Inc. An initial empirical model has been developed and provides results that are qualitatively consistent with the behavior of the PVDF films. A method and fixture for characterizing the piezoelectric properties of the materials has been developed and is being fabricated. Finally, an initial sample of the material to confirm test film design is suitable has been delivered.

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## Summary

In June 2010, Digital Fusion Solutions (DFS, a wholly-owned subsidiary of Kratos Defense and Security Solutions, Inc.) was awarded a contract for the development of optical quality flexible membrane mirrors. This report covers technical progress on this effort for the period 16 June – 15 September 2010. A report covering financial status for this period is provided separately. During this period, subcontracts were awarded to both team mates, Advanced Optical Systems, Inc. and NeXolve, Inc. An initial empirical model has been developed and provides results that are qualitatively consistent with the behavior of the PVDF films. A method and fixture for characterizing the piezoelectric properties of the materials has been developed and is being fabricated. Finally, an initial sample of the material to confirm test film design is suitable has been delivered.

## Introduction

DFS has teamed with Advanced Optical Systems, Inc (AOS) and NeXolve, Inc. to develop a breadboard system for demonstrating non-mechanical zoom using flexible thin films. The project consists of three major task area, which are Material Characterization, Diagnostic System Development, and Imaging System Development. DFS is responsible for leading the modeling effort, AOS is responsible for leading the optical design effort, and NeXolve is responsible for fabrication of the films. In addition, each member of the team supports the others in their areas of responsibility.

Material Characterization phase will involve two components: development of modeling tools and measurement of material properties for use in the tools. This phase is currently ongoing and will be discussed thoroughly in the next section. The Diagnostic System Development phase will apply the tools and knowledge developed in the first phase to build algorithms for modeling and testing one-dimensional films with multiple actuators. These models will then be compared to experimental results and modified as needed. The Imaging System Development phase will conclude the effort by building a sensor system with variable zoom based on optical quality PVDF films.

## Methods, Assumptions, and Procedures

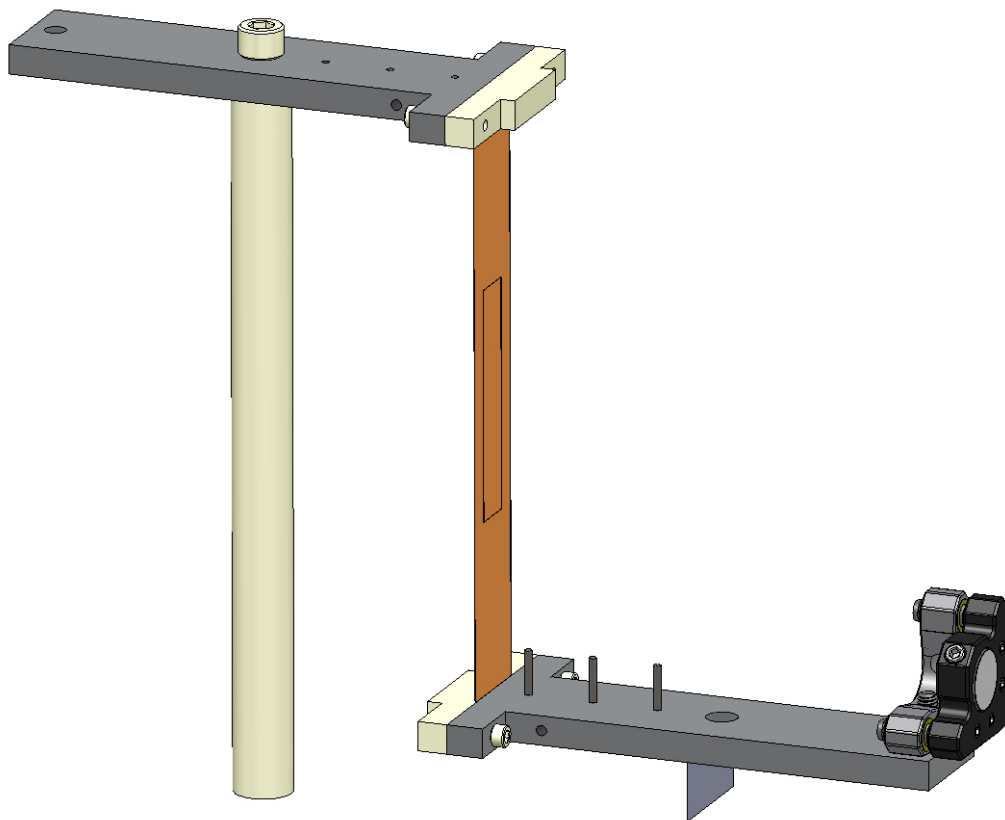
The first task addressed was working with a Navy sensor acquisition office to define the minimal requirements for these films to be used in a sensor system. For this task I met with Robert Borland of the F/A-18 Shared Reconnaissance Pod program office. Because of the early R&D nature of this project, it was difficult to define specific requirements. Two requirements that could be immediately identified were temperature performance and vibration response. For temperature, the films must be able to operate over the range 0 °C – 40 °C and survive over the range -40 °C – 60 °C. The upper limit is the most likely to cause an issue. As the film temperature is increased, the film loses its polling and its piezoelectric properties. NeXolve stated the polling is completely lost by about 130 °C, and expects little impact at temperatures of 60 °C. However, this will need to be confirmed as we move through the program. Vibration performance is naturally very program-specific. While we do not expect these films will be useful in an extremely dynamic environment like the F/A-18, less demanding environments such as unmanned aerial vehicles may be reasonable. Specifics will be addressed as the program matures.

While Mr. Borland was very interested in the technology, his interest was not in the area that might be expected. The focus of the solicitation and proposal was on the ability of the films for non-mechanical zoom and steering. His interest was on non-mechanical correction of thermal distortion. One of the current collection challenges is waiting for the optical system to reach equilibrium after taking off from a 50 °C environment and going to a 0 °C environment. The ability to adaptively correct for thermal distortion would be considered very useful. The non-mechanical zoom was considered less interesting, but could be useful if the degree of the zoom was substantially greater than the 3X minimum value being considered for this program. Mr. Borland stated he will discuss the program with the R&D group (Code 4.8) to see if there is interest on their part.

The modeling tools are based on interaction between three commercial software packages: SolidWorks, COMSOL Multiphysics, and ZEMAX optical design. SolidWorks is a computer aided design package, which as a live interface to COMSOL. COMSOL is a finite element analysis/partial differential equation solver. ZEMAX is an optical design package. Both COMSOL and ZEMAX have live interfaces to MatLab. Our initial investigations have enabled a model in SolidWorks to be updated in COMSOL, an FEA calculation performed in COMSOL, and data exported to MatLab. Independently, surface profile data has been exported from MatLab into ZEMAX. The next step will be to connect a single model from SolidWorks to ZEMAX. Future work will entail exporting optical computational results from ZEMAX into MatLab. From MatLab, the optical data will be used to alter the voltages driving the surfaces in COMSOL, and the cycle repeated. This will be computationally taxing, but will enable the development of approximations at a future time.

Modeling has focused on developing an empirical model for the film behavior and incorporating it into COMSOL. In the past, PVDF actuators were formed by combining two layers of materials that were poled with different orientations. The materials then act like a bimetallic strip used in a thermostat. Given the same field, one layer of the bimorph material would expand and one layer would contract, resulting in a curvature. This process is not amenable to optical quality films because of the distortion created by attaching the two films. NeXolve has developed a process that generates a curvature from a unimorph film that can be fabricated with an optical quality surface. Our current approach is modeling the material with piezoelectric constants that vary with depth into the film.

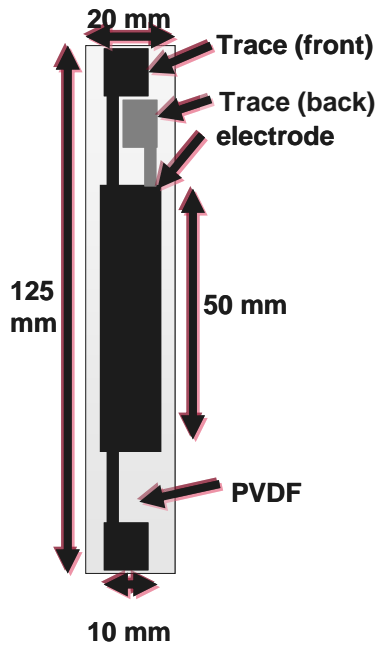
The current focus is on actual material characterization. The design of the test fixture for characterizing the material properties is shown in Figure 1. The upper bracket is used to connect the film to high voltage and hold it rigidly. The lower bracket is balanced on a knife edge, and will be used to connect the film to ground and apply a load to the film. There is a mirror mount on one end of the lower bracket. A laser will be reflected off this mount to measure deformations of the film as voltage is applied and the load is varied. Initial modeling using materials constants from the literature for PVDF indicate a deformation of ~0.4% in length can be expected with 1 kV applied. For our test samples with a 50 mm active area, that yields a deformation of 200  $\mu\text{m}$ . This deformation will result in a 4 mrad deflection of the laser spot, or about 10X larger than the estimated uncertainty is using the laser diode available in the lab.



**Figure 1. Material characterization test fixture (gray and black are aluminum, white is nylon, brown is PVDF)**

NeXolve has delivered an initial set of samples to evaluate the sample design. The purpose of these samples is not so much to characterize the materials, but to assess if the design of the samples will perform adequately in our test fixture. The design and a photograph of the evaluation samples are shown in Figure 2. The initial assessment of using one sample did not provide the expected performance, but the data is still being evaluated.

For the purpose of characterization, NeXolve will provide samples prepared from five different batches. Three batches will be nominally identical to assess the batch to batch variation. Three different film thicknesses (25, 50, 80  $\mu\text{m}$ ) will be evaluated to assess the variation of material properties with film thickness. From each batch two sets of samples will be created. Each set, consisting of 5 samples, will be cut from orthogonal directions to assess the variation in material properties with orientation. If the material performs as expected, not all of the samples will be tested, since the properties are expected to independent of orientation.



(a)



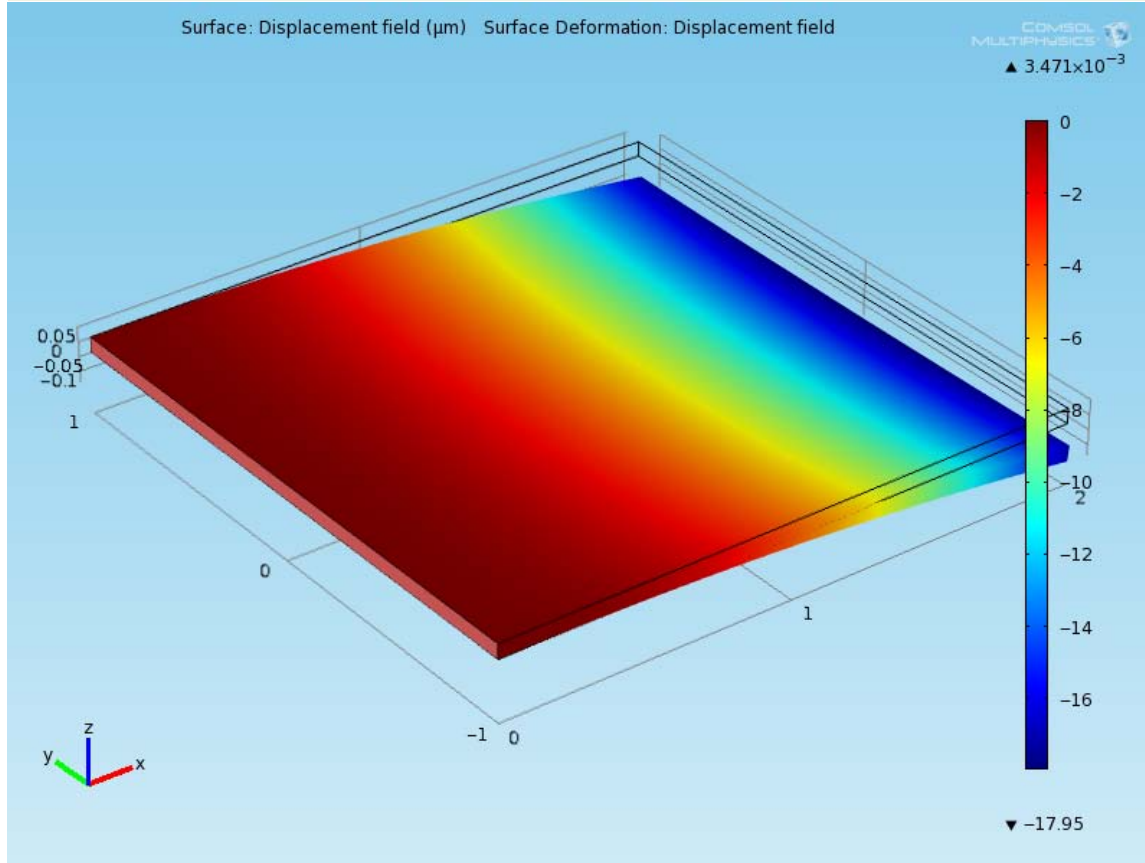
(b)

**Figure 2. (a) Dimensions of material characterization samples and (b) initial evaluation samples**

## Results and Discussion

One example of COMSOL results is shown in Figure 3. This figure was from a model which included a gradient in the piezoelectric constant which couples the  $z$ -axis electric field to the  $x$ -axis strain. This particular model included the  $x = 0$  surface constrained in the  $x$  direction. In addition to the negative curvature in the  $xz$  plane, there is a slight positive curvature in the  $yz$  plane. This curvature is seen from the curved lines of equal  $z$ -axis displacement, and results from Poisson's ratio. Poisson's ratio for a material relates the strain in one direction to the negative strain in the orthogonal direction. To confirm this explanation, another model was run with Poisson's ratio set to zero. The resulting surface had the lines of constant  $z$ -displacement straight and parallel to the  $y$ -axis.

Of the 18 evaluation samples provided, one sample has been briefly assessed by allowing the sample to hang freely and applying voltages to the electrodes. In contrast with previous films from NeXolve, this film showed very little deformation, even with the application of 4.5 kV. A laser was used to measure the angle of the surface deflection, with the deflection equal to roughly  $5^\circ$  at 3 kV. This is the order of magnitude of response expected when the film is constrained at the edges. There are several potential explanations for the behavior. The difference could be due to the smaller sample size and the linear configuration (previous films were substantially larger and circular, reducing the effects of the border around the active area of the film).



**Figure 3. Deformation plot for initial gradient piezoelectric model (deformation exaggerated by 7.5X). Overall dimensions 2 mm x 2 mm x 50  $\mu\text{m}$ .**

## Conclusions

Results to date are largely as expected. More testing needs to be completed and data analyzed on the evaluation samples to determine why the response is smaller than previous films. Otherwise, the program should continue as planned.